Results of Neurofeedback in Treatment of Children with ADHD: A Systematic Review of Randomized Controlled Trials

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Authors' contributions: In this review article Inmaculada Moreno-García had the idea for the article, Inmaculada Moreno-García and Almudena Cano-Crespo performed the literature search and data analysis, and Inmaculada Moreno-García, Almudena Cano-Crespo and Francisco Rivera drafted and critically revised the work.

Abstract

Attention-Deficit/Hyperactivity Disorder (ADHD) is one of the most prevalent disorders in children and adolescents. Neurofeedback, a nonpharmaceutical treatment, has shown promising results. *Objective:* To review the evidence of efficacy of neurofeedback as a treatment for children and adolescents with ADHD. *Method:* A systematic review of the specific scientific studies published in 1995-2021, identifying and analyzing randomized controlled trials (RCT). *Results:* A total of 1636 articles were identified and 165 met inclusion criteria, of which 67 were RCTs. *Conclusion:* Neurofeedback training was associated with significant long-term reduction in symptoms of ADHD. Though limitations exist regarding conclusions about the specific effects of neurofeedback, the review documents improvements in school, social, and family environments.

Keywords: neurofeedback, treatment, ADHD, children

Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is characterized by a persistent pattern of inattention and/or hyperactivity and impulsivity which affects a child's social, occupational or academic functioning. Severity of symptoms varies from light to moderate to severe and clinical presentations include predominantly inattention, hyperactivity/impulsivity or a combination of them (American Psychiatric Association, 2013). There is no single or universal treatment for this disorder. Danielson et al. (2018) described the range of treatments in A National Description of Treatment among United States Children and Adolescents with Attention-Deficit/Hyperactivity Disorder, which followed up parents of children (4-17) with ADHD starting in 2011 who received four main types of treatment: medication, psychosocial intervention, school support and alternative treatments. Of these children, 67% received the first three types of treatment and 7% none. Psychological treatments included training in social skills (39%), training for parents (31%), peer intervention (30%), cognitive behavioral therapy (20%), alternative treatments (e.g., dietary supplements) (9%) and neurofeedback (11%). Neurofeedback is one of the neuroregulation techniques (Gevensleben et al., 2014), which are posited to produce changes in the subject's neural activity. Research on neurofeedback has demonstrated an irregular EEG pattern (reduced activity of beta waves and increased theta) in most children with ADHD (Janssen et al., 2017; Snyder & Hall, 2006; Loo & Makeig, 2012). Theta/beta ratio (TBR) training and slow cortical potential training (SCP) have received the most support and evidence for treatment of ADHD (Gevensleben et al., 2014; Monastra et al., 2005). In view of the sometimes contradictory data on neurofeedback treatment, researchers endorse the need for more randomized controlled trials (RCT).

One of the first studies that analyzed the efficacy of neurofeedback for ADHD treatment was done by Rossiter and La Vaque (1995), who used a group design to compare neurofeedback with psychostimulants. Lubar et al. (1995), compared neurofeedback with treatment using methylphenidate (MPH) in a clinic setting. In a case series by Thompson and Thompson (1998), neurofeedback was applied along with other learning strategies and showed significant improvement on various evaluation scales including IQ. Reviews and meta-analyses by Lofthouse et al. (2012), Gaviria et al. (2014) and Micoulaud-Franchi et al. (2014), concluded that application of different forms of neurofeedback were effective. Their beneficial effects are maintained in some cases up to six months after treatment (Arns et al., 2009; Meisel et al., 2013; Steiner et al., 2014), in others, from 2 to 12 months posttreatment (Van Doren et al., 2019) and in one, for two years (Gani et al., 2008). The meta-analysis by Riesco-Matías et al. (2021) supported the efficacy of neurofeedback and proposed a

relationship between what is learned by the subject during neurofeedback training, ADHD symptoms and neurophysiological measurements.

Among the publications reporting on RCT, Lubar et al. (1995) found significant improvement post-training in TOVA, ADDES and WISC-R performance. Vollebregt et al. (2014) found no difference between treatment groups with neurofeedback and a placebo, but Geladé et al. (2018) did conclude that the neurofeedback group had better results than the one with physical activity. Rubia et al., (2019) also found improvement in the two neurofeedback treatment groups that they studied. Concerning evidence of neurofeedback as a treatment for ADHD, some studies have concluded that neurofeedback is "effective" as a treatment for ADHD (Arns et al., 2009), "probably effective" (Lofthouse et al., 2012) or "possibly effective" (Storebø et al., 2011). Along the same line as Monastra et al. (2005), the review by Sampedro-Baena et al. (2021) suggested that as there is no conclusive RCT research, more RCTs need to be published.

The objective of this study was to review the evidence regarding the efficacy of neurofeedback as a treatment for children and adolescents with ADHD by means of a systematic review of RCTs. Scientific productivity, reflected in growth in the number of studies, as well as its geographic distribution and the journals that published the studies during the twenty-seven year study period, were analyzed for this purpose.

Method

This systematic review was performed following the guidelines of the PRISMA Declaration (Page et al., 2021). A search was made in the PsycINFO and Medline (PubMed) databases on December 1, 2021. The search strategy, including the keywords, Boolean operators and search fields, was the following:

Title or Abstract = ADHD AND ("Attention Deficit Disorder" OR "Attention Deficit Disorder with Hyperactivity"); AND Title or Abstract = Neurofeedback OR "EEG Biofeedback"; AND Title or Abstract = Treatment; AND Title or Abstract = "Randomized Controlled Trial".

The search period delimited was from January 1995 to December 2021. This period was selected because most of the published evidence available on-line concerning the use of neurofeedback for the treatment of ADHD dates from 1995, though Lubar published a case study concerning effective treatment of a hyperkinetic child using neurofeedback as early as 1976.

The inclusion criteria were the following: *a)* articles published in peer-reviewed journals that included neurofeedback as a treatment for ADHD; *b)* participants aged 6 to 18; *c)* participants with primary diagnosis ADHD (as inclusion criteria in the articles), including subtypes/clinical presentations, regardless of the

diagnostic manual used; and *d)* articles in which neurofeedback had been administered as the only treatment option and/or combined with other treatments (medication, behavioral therapy, etc.).

The exclusion criteria were: *a)* papers and chapters in books on the subject, not published in peer-reviewed journals; *b)* neurofeedback concept, descriptive and/or explanatory articles; *c)* studies with participants not diagnosed with ADHD or with comorbid disorders/alterations (physical or psychological) along with this disorder, such as obsessive-compulsive disorder, tics or intellectual disability, among others; *d)* articles replicating or commenting on previous publications; *e)* duplicate studies in the databases (eliminated in one of them); *f)* other types of EEG; and *g)* publications that refer to neurofeedback as a treatment but not as the main intervention of the study.

Neither publication language nor country of origin of authors was considered a criterion for exclusion. Nor were studies excluded because of the measures used (attention, behavior control, etc.), the results, sample size, treatment conditions or neurofeedback application procedure.

Study selection was based on inclusion and exclusion criteria when examining the titles, abstracts, and having surpassed that stage, review of the complete text to evaluate their pertinence according to the specified criteria. To ensure evaluation reliability, 20% of the articles were chosen at random to be analyzed independently by a second examiner who did not know the first examiner's decision. Agreement between reviewers on the inclusion of articles was estimated using Cohen's kappa, finding a coefficient of 0.9, which shows good agreement (Hallgren, 2012).

Once the studies had been selected using the criteria mentioned, and in view of the possibility that there could be some publication not included in the databases reviewed, the procedure in Willis et al. (2011) and Van Doren et al. (2019) was followed, making a manual search in the references listed. By following this protocol before the review, possible risk of bias was reduced. In the table synthesizing results, publications included in the database search are marked with an * and those included in the complementary search are marked ●.

Data extraction was done using a table created for the purpose that included the main bibliometric characteristics of the study (authors, year of publication, journal, author country of origin), description of the study participants (sample size, age range and gender distribution), as well as study methodology characteristics (study design, number of sessions and length of intervention and evaluation instruments) and the main findings concerning neurofeedback. Extraction table adequacy was checked in a pilot test and was reviewed by the whole research team. To ensure data extraction quality, 20% of the records were selected and

were reviewed by a third-party professional not involved in the extraction. The result showed a negligable number of discrepancies that did not affect the conclusions derived.

Results

At first, a total of 1636 publications were identified that met the descriptors: 276 (17%) publications in PsycINFO and 1360 (83%) in PubMed. After eliminating duplicates and screening for time period and age, 216 publications remained, of which only 165 met the inclusion criteria. This process is shown in a PRISMA flow diagram in Figure 1.

(INSERT FIGURE 1 ABOUT HERE)

Fig. 1 PRISMA 2020 flow diagram for search in databases and other sources. Adapted from "The PRISMA 2020 statement: an updated guideline for reporting systematic reviews", M.J. Page et al., 2021, BMJ (Clinical research ed.), 372, n160. https://doi.org/10.1136/bmj.n160

After the search in the lists of references, 53 more articles were included, for a total of 165 articles that met the criteria mentioned. Thus, 76% of the studies identified in PsycINFO and 43% in PubMed were included. That is over 65% (67%) of the studies originally selected.

Of the studies selected (Table 1) 67 were RCTs. The historical evolution of the scientific productivity was examined, considering country of origin and journals where they were published. When the historical evolution of the data was analyzed (Figure 2) in four-year range groups, growth in number of publications is observed. Geographically (Figure 3), the studies were concentrated in Germany (16 studies), the Netherlands (11) and the United States (11), while the rest of the countries contributed three or fewer publications. Finally, with regard to the journals containing the RCT (Figure 4), 42 different journals were identified, in which the largest number were in the European Journal of Child & Adolescent Psychiatry (7), Journal of Attention Disorders (4) and BMC Psychiatry (4), which contained the highest number of publications

(INSERT TABLE 1 ABOUT HERE)

Table 1 Year, journal and country of each randomized controlled trial included

(INSERT FIGURE 2 ABOUT HERE)

Fig. 2 Historical evolution by period of years of studies with randomized controlled trials included in this review

(INSERT FIGURE 3 ABOUT HERE)

Fig. 3 Geographic distribution by country of origin of studies with randomized controlled trial design included in this review

(INSERT FIGURE 4 ABOUT HERE)

Fig. 4 Journals that have published at least one randomized controlled trial during the period reviewed

The detailed analysis of the studies reviewed may be seen in Table 2, showing the study author/s, year, country, participants (sample size, age, sex, ADHD subtypes), treatment, therapeutic sessions (total number of sessions, periodicity and duration), evaluation instruments and results, etc. Table 3 shows the instruments, evaluation techniques and treatment. There was only one possible case of bias in a study which, although it apparently met all the criteria for inclusion, was not included, since it did not specify whether the participants had other comorbid disorders.

(INSERT TABLE 2 ABOUT HERE)

Table 2 Synthesis of studies reviewed: randomized controlled trials. Design, participants and significant results.

(INSERT TABLE 3 ABOUT HERE)

Table 3 List of instruments, evaluation techniques used and treatments administered in the studies reviewed

The publications selected were analyzed for the following variables: participants, number of neurofeedback sessions and their duration, and neurofeedback protocols applied. The results showed that overall, 4980 children received neurofeedback. Of the total studies included (n = 67), 30 (45% included a sample size ≤ 50 participants, and 37 (55%) > 50. Similarly, 2041 treatment sessions were given, lasting about 20-60 minutes. The TBR and SCP training protocols were used the most (Table 2).

After the articles had been reviewed, in general, neurofeedback was found to produce beneficial effects, such as reduction in measured core ADHD symptoms of inattention, hyperactivity and/or impulsivity, intelligence and other altered behaviors, like opposition and physical aggression, social and school variables.

Specifically concerning improvement in core ADHD measurements, the studies by Aggensteiner et al. (2021), Gevensleben et al. (2009), Van Dongen-Boomsma et al. (2013), Bakhshayesh et al. (2010), Bakhshayesh et al. (2011), Gevensleben et al. (2013), Johnstone et al. (2017), Lee and Jung (2017), Strehl et al. (2017), van Dongen-Boomsma et al. (2014), Wangler et al. (2011), and Zhonggui et al. (2005) showed that neurofeedback was effective to a significant degree 73.3% of the cases. In the study by Maurizio et al. (2014), these improvements had a medium effect size (d = .52) in primary ADHD symptoms. In the publication by Liechti et al. (2012), the behavioral improvements found in children were significants, with medium-large effects, as measured by both parents (p = .024) and teachers (p = .041). Cho et al. (2004) observed a significant

increase ($p < .01$) in selective attention, better information management and less impulsivity. Gevensleben et al. (2014) mentioned that effects were better for inattention ($d = 1$) than for hyperactivity/impulsivity ($d = .43$). The article by Beauregard and Lévesque (2006) and Lévesque et al. (2006) included an experimental (neurofeedback) and control groups. Neurofeedback resulted in brain activity changes normalizing selective attention and response inhibition in children with ADHD compared to the control group.

When improvement in core ADHD measurements was compared to other treatments, Bink et al. (2014) found medium ($d = .54$) improvement in attention and psychomotor speed in the group that received neurofeedback compared to the control group. Gevensleben et al. (2010) and Gevensleben, Moll and Heinrich (2010) found an effect of neurofeedback of $d = .60$ compared to cognitive training. Other studies by DeBeus and Kaiser (2011), Keith et al. (2015) and Steiner et al. (2011), comparing neurofeedback with control groups and placebo, found improvement in inattention, with a medium effect size ($d \geq .50$). When comparing neurofeedback to cognitive training, Cho et al. (2002) also showed that the difference was significant ($p < .05$). Moreno-García et al. (2015) found improved scores in auditory and visual attention in both the neurofeedback group and the groups that received medication and behavioral therapy, although without statistically significant differences between groups. Steiner et al. (2014) found significant improvements in ADHD symptoms in school children who received neurofeedback in a school setting as compared to cognitive and control training with a moderate effect size ($d = .43$). Steiner et al. (2014) compared the dose of methylphenidate participants were prescribed before and after intervention and recorded significant increases both in children who received cognitive training and in the control group (7.05 mg and 8.54 mg, respectively, $p < .05$), while the increase in dose was minimal in the neurofeedback group (0.29 mg, $p = .47$). The Neurofeedback Collaborative group study also found a much smaller increase in dose of stimulant medication in the neurofeedback group at follow-up, as compared to the sham control group. Both groups showed significant gains, which underscores the role of non-specific effects. The study outlined by Bioulac et al. (2019) and developed by Purper-Ouakil et al. (2021), showed significant improvement in both groups in ADHD symptoms, as well as in secondary outcomes.

With regard to the reduction in core ADHD symptoms when combined with other treatments, the study by Christiansen et al. (2014) found similar results in the neurofeedback and behavioral therapy groups, and Duric et al. (2017) found the most significant effects with combined neurofeedback and methylphenidate. Li et al. (2013) found that this combined treatment resulted in more significant improvements (maintained after

six months) than with medication alone with respect to ADHD symptoms ($p < .05$), social functioning ($p < .001$) and smaller increase in methylphenidate dose ($p < .05$).

Effects achieved by neurofeedback on improved ADHD symptoms were maintained for 2 to 24 months. In the study by Mohagheghi et al. (2017). These effects appeared after two months and in the studies by Christiansen et al. (2014), Duric et al. (2017), Lansbergen et al. (2011), Leins et al. (2007), Li et al. (2013) and Meisel et al. (2013) the improvement in ADHD symptoms was maintained up to six months. These benefits were maintained for a period of over six months in the results reported by Gani et al. (2008) (6-24 months), Alegría et al. (2017) (11 months), Dobrakowski and Lebecka (2020) (12 months) and Neurofeedback Collaborative Group (2021) (13 months). Gani et al. (2008) included a follow-up evaluation carried out not only 6 months after the last training session, but also, they presented data 2 years after the end of the treatment. This was one of the first long-term RCT study including such a long period of time of follow-up, showing that clinical outcome and self-regulation skills maintained invariable, and in some cases, presenting improvements.

Referring to the improvement in other noncore ADHD behaviors or measurements, the studies by Lubar et al. (1995) and Linden et al. (1996) recorded a significant 10 point increase in intelligence scores with neurofeedback. Furthermore, among the effects of neurofeedback, Bink et al. (2015) found a reduction in other behavioral problems in the group of usual treatment and in the one combined with neurofeedback. Holtmann et al. (2009) found that the neurofeedback group had better results than cognitive training in behaviors such as opposition and physical aggression and Duric et al. (2014) found that neurofeedback led to significant improvements with large effect sizes in attention ($d = .90$) and hyperactivity ($d = .57$), and medium effect size in school performance ($d = .55$). Gevensleben et al. (2009) also reported a reduction of ADHD symptoms and of other associated problems, such as social adaptation, finding medium effects ($d = .60$) when neurofeedback was compared to cognitive training.

However, findings are not consistent across all studies. There are results that did not demonstrate improvement in ADHD symptoms. The publications by Duric et al. (2012) and van Dongen-Boomsma et al. (2015) did not find any significant difference in primary ADHD symptoms when the neurofeedback group was compared to the other study groups (medication and placebo). Neither did Vollebregt et al. (2014) find any significant differences in core symptoms between the neurofeedback group and placebo group. Heywood and Beale (2003) found that the placebo group was better than neurofeedback, although the effect was small ($d = .24$). Another group of results showed that the comparison group (placebo, medication with methylphenidate and dextroamphetamine, acupuncture and physical activity) showed better results than neurofeedback in

reducing inattention, hyperactivity and/or impulsivity (Arnold et al., 2013; Ogrim & Hestad, 2013; Perreau-Linck et al., 2010). He et al. (2014) found that the combination of acupuncture and neurofeedback had better scores on intelligence and ADHD symptoms, with a total efficacy rate of 91.5% in acupuncture plus neurofeedback and 83.3% in neurofeedback alone. Janssen et al. (2016) recorded improvements in brain function, more specifically, improved response inhibition, with medication ($p < .001$) than with neurofeedback ($p = .240$) and physical activity ($p = .425$). Comparing these three groups, Geladé et al. (2016), Geladé et al. (2017) and Geladé et al. (2018) concluded that methylphenidate was superior to both neurofeedback and physical activity in reducing symptoms in children with ADHD with a medium effect size ($\approx d = .5$). However, in the six-month postintervention follow-up, Geladé et al. (2018) found no significant difference.

Discussion

The objective of this study was to review the efficacy of neurofeedback as a treatment for children and adolescents with ADHD by means of a systematic review of RCTs conducted in the last 27 years. For this purpose, the main characteristics of these studies were analyzed in terms of scientific productivity and their geographic and temporal distribution.

The review concluded that there has been an increase in the number of studies with a RCT design, scientific productivity has grown in recent years; and the highest number of publications came from Germany. Insofar as evidence concerning the effectiveness of neurofeedback, it was observed to be effective in over half of the RCTs reviewed, with beneficial effects on intelligence, oppositional behavior, aggression and social and school functioning. However, data were not consistent across the studies concerning the maintenance of these effects.

When the results were analyzed, it was observed that our criterion concerning studies with participants without an ADHD diagnosis or with comorbid disorders/alterations, was the most restrictive, as it led to exclusion of a large number of studies that had previously been selected. Although in publications, such as the review by Lofthouse et al. (2011), studies with participants with comorbid disorders were specified, we did not find any study that excluded publications according to this criterion. In this case, in order to focus on the objective of the study of the effects of neurofeedback on ADHD with no comorbidity, this exclusion criterion was considered necessary.

In this review, most of the studies included are RCTs. These data are contradictory to the findings of Gaviria et al. (2014), perhaps because, in that study, scientific reviews prevailed, and, it should be taken into

account that fewer studies were reviewed by those authors, which could explain the differences with respect to their conclusions and the results reported here.

The data extracted demonstrate the increase in scientific productivity in RCTs, in agreement with Servera and Moreno (2019), who observed a progressive increase in these publications since the nineties. The findings on countries where the scientific productivity was concentrated partly coincides with the results of Gaviria et al. (2014). This study differs because the USA ties with the Netherlands for second place, as opposed to the findings of those authors which position Switzerland as the country where research productivity was high. Of the 67 randomized controlled trials reviewed, 38 (56%) came from Germany, the Netherlands and USA. Norway was in third place with 4 studies and Switzerland, with 3 studies, tied for fourth place with Canada, China, Korea and Spain. England, France and Iran contributed 2 studies each, while Australia, New Zealand, Poland and Sweden all published 1 RCT.

Evidence on neurofeedback and its beneficial effects is consistent with the findings by Holtmann et al. (2014) and Weber et al. (2020) indicating that neurofeedback significantly improves primary symptoms of ADHD. In this study, the effects were particularly observed in attention and impulsivity and, to a lesser extent, in hyperactivity. Progress in this direction comes from the results found by Weber et al. (2020), which identified in the studies reviewed, various predictors that favored the efficacy of neurofeedback. Among them, they included as possible predictors, the electrophysiological baseline measures of the participants, such as presenting higher activation at baseline, before training sessions. Furthermore, other predictors could be based on the initial training phase, examining the learning ability of the participants by evaluating the performance in training sessions. This could predict future training execution, rather than employing the usual baseline parameters before the first training session. In the recent review by Sampedro-Baena et al. (2021), the combination of neurofeedback with other types of intervention, such as behavioral therapy and physical activity, achieved better clinical results.

Nevertheless, as the results show, these effects are not conclusive in all the studies reviewed. Such findings agree with the results extracted in the meta-analysis done by Van Doren et al. (2019). That study demonstrated that the effects are not universal, as neurofeedback did not improve the core symptoms of ADHD, or other associated symptoms, in all the studies reviewed, studies in which the children continued taking medication even during neurofeedback treatment. Some years before that, the review by Willis et al. (2011) also had shown contradictory results on the effects of neurofeedback. The review by Rubia et al. (2021)

also concluded that more systematic studies are necessary to clarify the specific effects of neurofeedback and its clinical implications.

Our findings agree with the study by Holtmann et al. (2014), which concluded that the effects of neurofeedback were maintained in the long term, from 6 to 24 months after treatment. Maintenance of these effects, confirmed in a number of the studies we have reviewed, establishes lasting effects as an added advantage of neurofeedback over other types of treatment such as medicating where effects do not last in the long term. This was also among the conclusions of the meta-analysis by Arns et al. (2009). Furthermore, the review by García-Pimenta et al. (2021), showed that multimodal designs including personalized application of neurofeedback showed better results than its application alone and compared to medication. In addition, the paper by Louthrenoo et al. (2021) concluded that it was also important to include information about executive function outcomes based on neuropsychological evaluation when applying neurofeedback. Finally, the study by Arns et al. (2020) strongly recommend that it should be applied in compliance with the guidelines proposed by organizations specialized in neurofeedback.

The limitations of this study derive mainly from the heterogeneity of the studies reviewed. They differ in methodology, characteristics and inclusion criteria of the participants, mostly obviating the incorporation of the participants to the groups by psychophysiological criteria, an issue that, if carried out, would make possible the administration of specific training protocols according to different endophenotypes. This is a limitation of the works reviewed, which, in addition, differ in training protocols, equipment used, evaluation instruments, measures of efficacy and statistical analyses, thus impeding the extraction of conclusive results concerning the evidence for neurofeedback's efficacy. Nevertheless, the wide period covered by the current analysis is an important addition to the literature. By covering all the RCT of neurofeedback for ADHD conducted across the past 27 years, this review provides an up-to-date panorama of scientific research on the subject. Still pending for future research is an extension of this review to other databases and sources and widening the search criteria to include other relevant studies. Perhaps greater standardization of methods for applying neurofeedback, the management of psychophysiological criteria for the inclusion of participants in the different randomized groups, will facilitate the administration of specific training protocols and, consequently, a wider and more adapted application of its use will generate further RCT evidence that will facilitate meta-analyses that would make it possible to elucidate the specific effects of neurofeedback training in the treatment of ADHD.

Declarations

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Conflicts of interest/ Competing interests

The authors declare that they have no conflict of interest, excluding the above.

Ethics approval

This systematic review was performed following the guidelines and protocols PRISMA, PRISMA-P (Page et al., 2021).

Consent

Not applicable

Data, Material and/or Code availability

Not applicable, all data generated or analyzed during this study are included in this published article.

Authors' contributions

In this review article Inmaculada Moreno-García had the idea for the article, Inmaculada Moreno-García and Almudena Cano-Crespo performed the literature search and data analysis, and Inmaculada Moreno-García, Almudena Cano-Crespo and Francisco Rivera drafted and critically revised the work.

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Figure 1

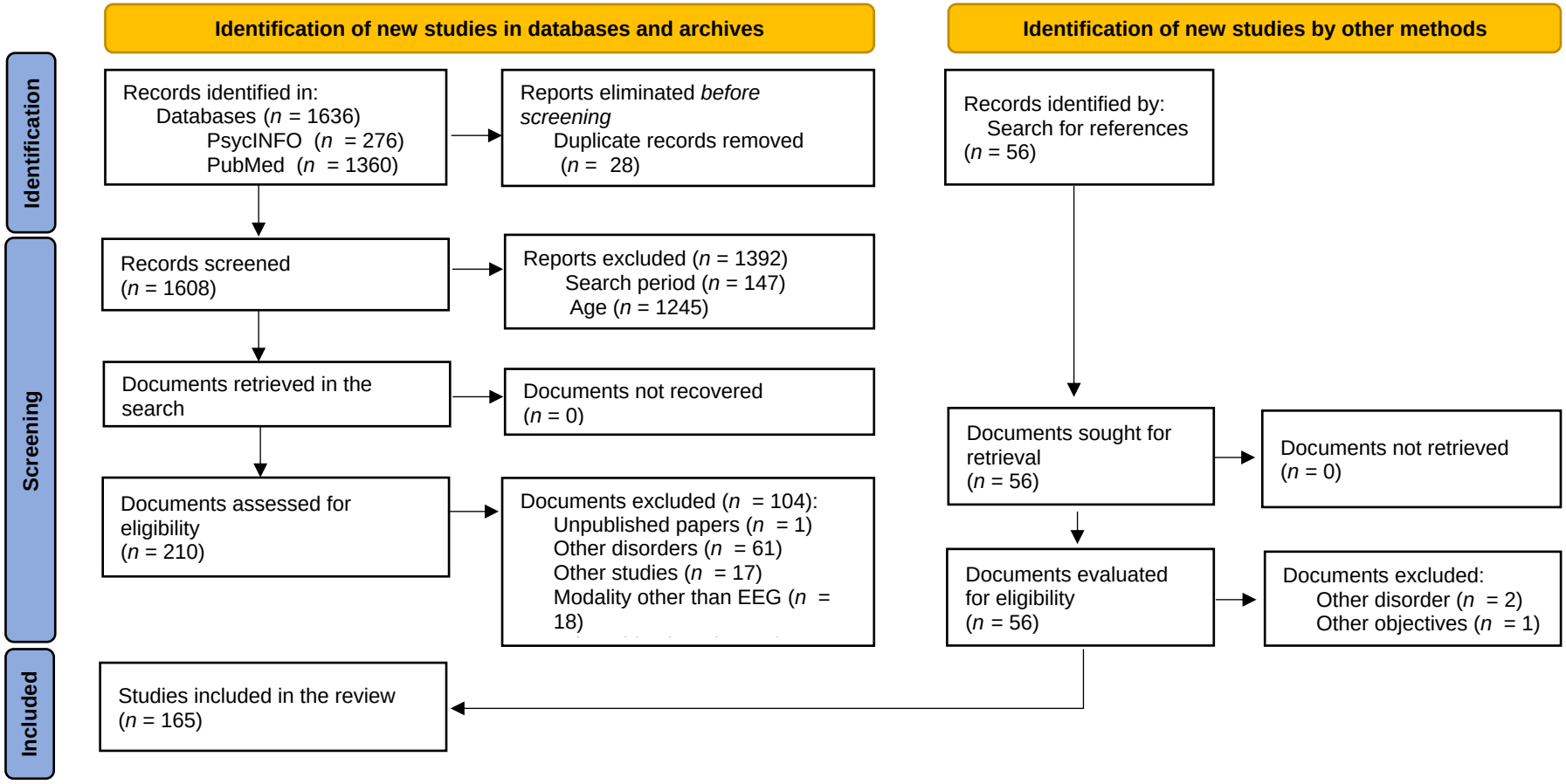
Identification of new studies in databases and archives
Identification of new studies by other methods
Identification
Screening
Included
Records identified in:
Databases (n = 1636)
PsycINFO (n = 276)
PubMed (n = 1360)
Reports eliminated before screening
Duplicate records removed
(n = 28)
Records identified by:
Search for references
(n = 56)
Records screened
(n = 1608)
Reports excluded (n = 1392)
Search period (n = 147)
Age (n = 1245)
Documents retrieved in the search
Documents not recovered
(n = 0)
Documents sought for retrieval
(n = 56)
Documents not retrieved
(n = 0)
Documents assessed for eligibility
(n = 210)
Documents excluded (n = 104):
Unpublished papers (n = 1)
Other disorders (n = 61)
Other studies (n = 17)
Modality other than EEG (n = 18)
Documents evaluated for eligibility
(n = 56)
Documents excluded:
Other disorder (n = 2)
Other objectives (n = 1)
Studies included in the review
(n = 165)

Table 1

Year, journal and country of each randomized controlled trial included

Year	Journal	Country
Lubar et al. (1995)	Biofeedback and Self-Regulation	USA
Linden et al. (1996)	Biofeedback and Self-Regulation	USA
Cho et al. (2002)	Studies in Health Technology and Informatics	Korea
Heywood & Beale (2003)	Journal of Attention Disorders	New Zealand
Cho et al. (2004)	CyberPsychology and Behavior	Korea
Zhonggui et al. (2005)	Journal of Huazhong University of Science and Technology [Medical Sciences]	China
Lévesque et al. (2006)	Neuroscience Letter	Canada
Beauregard & Lévesque (2006)	Applied Psychophysiology and Biofeedback	Canada
Leins et al. (2007)	Applied Psychophysiology and Biofeedback	Germany
Gani et al. (2008)	International Journal of Bioelectromagnetism	Germany
Holtmann et al. (2009)	Kindheit und Entwicklung	Germany
Gevensleben, Holl, Albrecht, Vogel et al. (2009)	Journal of Child Psychology and Psychiatry	Germany
Gevensleben, Holl, Albrecht, Schlamp et al. (2009)	International Journal of Psychophysiology	Germany
Perreau-Linck et al. (2010)	Journal of Neurotherapy	Canada
Bakhshayesh et al. (2010)	Psychological Research	Germany
Gevensleben, Holl et al. (2010)	European Child & Adolescent Psychiatry	Germany

Gevensleben, Moll & Heinrich (2010)	Zeitschrift für Kinder und Jugendpsychiatrie Psychotherapie.	Germany
DeBeus & Kaiser (2011)	Neurofeedback and Neuromodulation Techniques and Applications	USA
Lansbergen et al. (2011)	Journal of Neural Transmission	Netherlands
Wangler et al. (2011)	Clinical Neurophysiology	Germany
Steiner et al. (2011)	Clinical Pediatrics	USA
Bakhshayesh et al. (2011)	European Child & Adolescent Psychiatry	USA
Duric et al. (2012)	BMC Psychiatry	Norway
Liechti et al. (2012)	Clinical Neurophysiology	Switzerland
Russell-Chapin et al. (2013)	Journal of Neurotherapy	USA
Arnold et al. (2013)	Journal of Attention Disorders	USA
Kerson (2013)	Journal of Attention Disorders	USA
van Dongen-Boomsma et al. (2013)	Journal of Clinical Psychiatry	Netherlands
Li et al. (2013)	Swiss Medical Weekly	China
Meisel et al. (2013)	Biological Psychology	Spain
Ogrim & Hestad (2013)	Journal of Child and Adolescent Psychopharmacology	Norway
Vollebregt et al. (2014)	Journal of Child Psychology and Psychiatry	Netherlands
Maurizio et al. (2014)	Biological Psychology	Switzerland
Gevensleben et al. (2014)	Brain Topography	Germany
Steiner et al. (2014)	Journal of Developmental and Behavioral	USA

	Pediatrics	
Steiner et al. (2014)	Pediatrics	USA
Holtmann et al. (2014)	BMC Psychiatry	Germany
He et al. (2014)	Zhongguo Zhen Jiu	China
Bink et al. (2014)	European Child & Adolescent Psychiatry	Netherlands
Duric et al. (2014)	Neuropsychiatric Disease and Treatment	Norway
Christiansen et al. (2014)	Frontiers in Human Neuroscience	Germany
van Dongen-Boomsma et al. (2015)	Tijdschrift voor Psychiatrie	Netherlands
Keith et al. (2015)	Psychology of Addictive Behaviors	USA
Bink et al. (2015)	The Journal of Clinical Psychiatry	Netherlands
Moreno-García et al. (2015)	International Journal of Clinical and Health Psychology	Spain
Janssen et al. (2016)	Journal of Child and Adolescent Psychopharmacology	Netherlands
Hasslinger et al. (2016)	Translational Developmental Psychiatry	Sweden
Geladé et al. (2016)	The Journal of Clinical Psychiatry	Netherlands
Moreno-García et al. (2019)	Journal of Attention Disorders	Spain
Blume et al. (2017)	Trials	Germany
Mohagheghi et al. (2017)	BioMed Research International	Iran
Lee y Jung (2017)	Asian Journal of Psychiatry	Korea
Strehl et al. (2017)	Frontiers in Human Neuroscience	Germany
Geladé et al. (2017)	European Child & Adolescent Psychiatry	Netherlands

Janssen et al. (2017)	European Child & Adolescent Psychiatry	Netherlands
Alegría et al. (2017)	Human Brain Mapping	United Kingdom
Johnstone et al. (2017)	International Journal of Psychophysiology	Australia
Duric et al. (2017)	Nordic Journal of Psychiatry	Norway
Döpfner et al. (2017)	BMC Psychiatry	Germany
Geladé et al. (2018)	European Child & Adolescent Psychiatry	Netherlands
Minder et al. (2018)	European Child & Adolescent Psychiatry	Switzerland
Rubia et al. (2019)	NeuroImage	USA
Bioulac et al. (2019)	BMC Psychiatry	France
Dobrakowski & Lebecka (2020)	Clinical EEG and Neuroscience	Poland
Purper-Ouakil et al. (2021)	Journal of Child Psychology and Psychiatry	France
The Neurofeedback Collaborative Group (2021)	Journal of the American Academy of Child and Adolescent Psychiatry	USA
Aggensteiner et al. (2021)	Biological Psychology	Germany

Figure 2

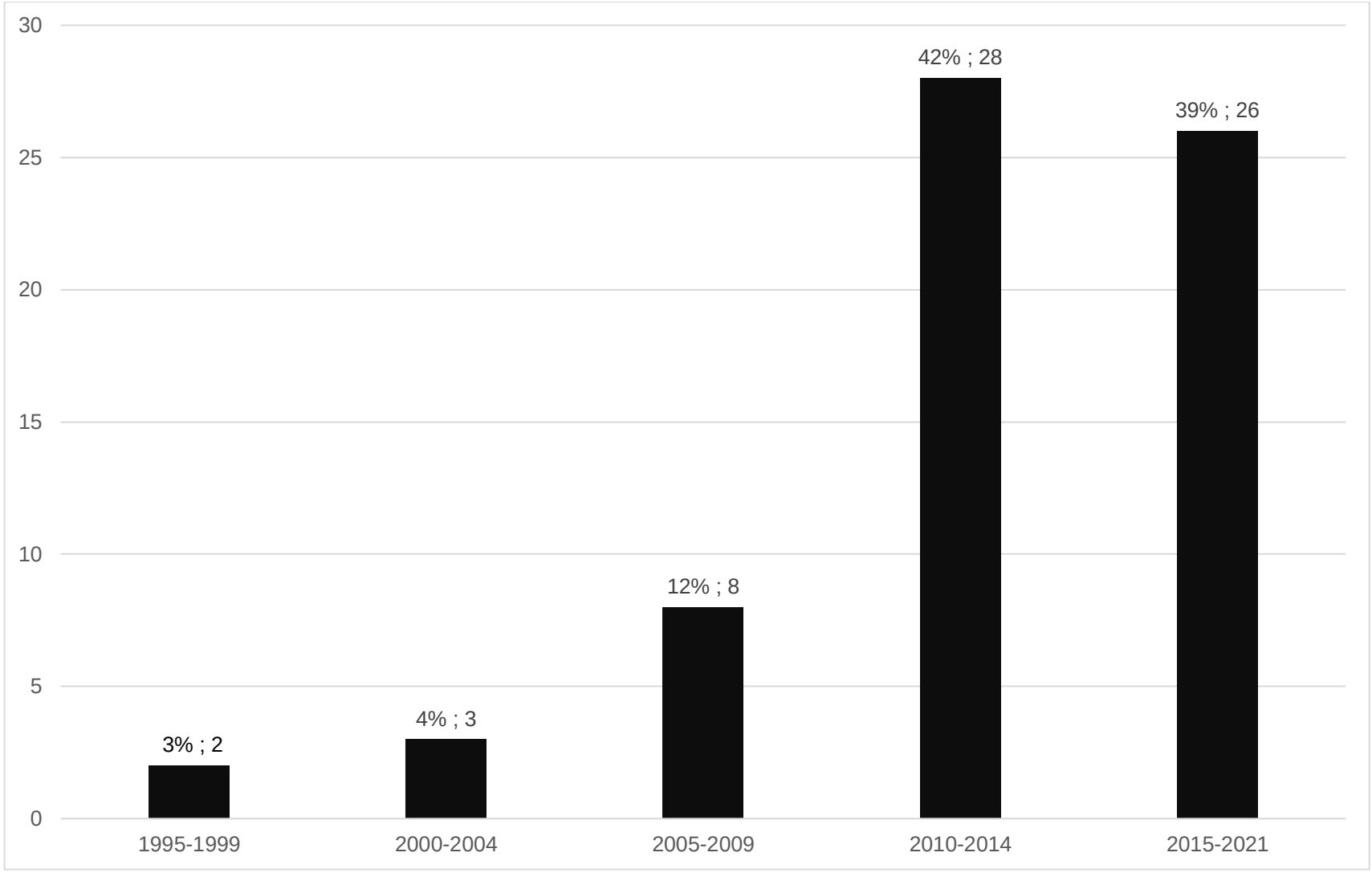
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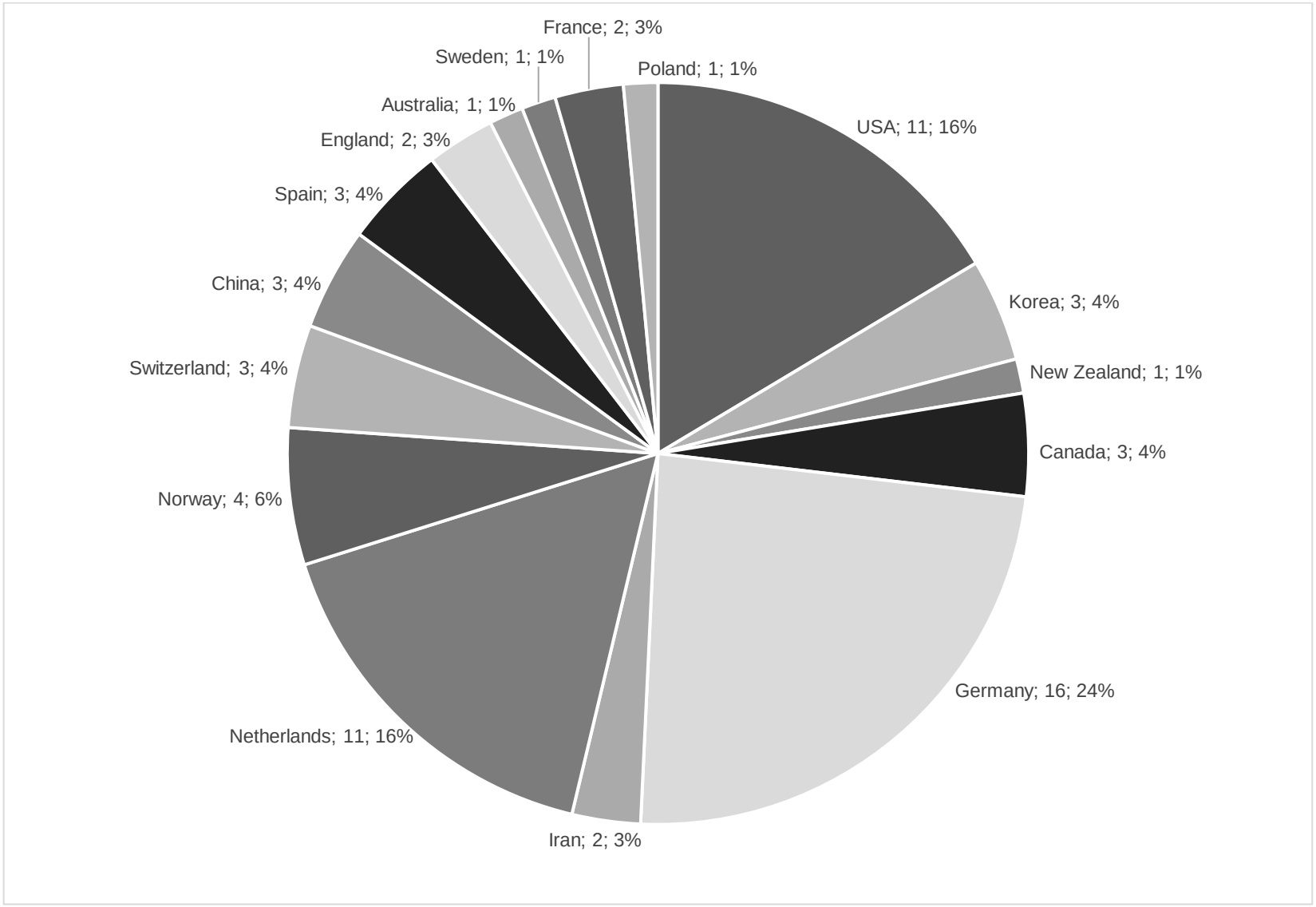
Figure 3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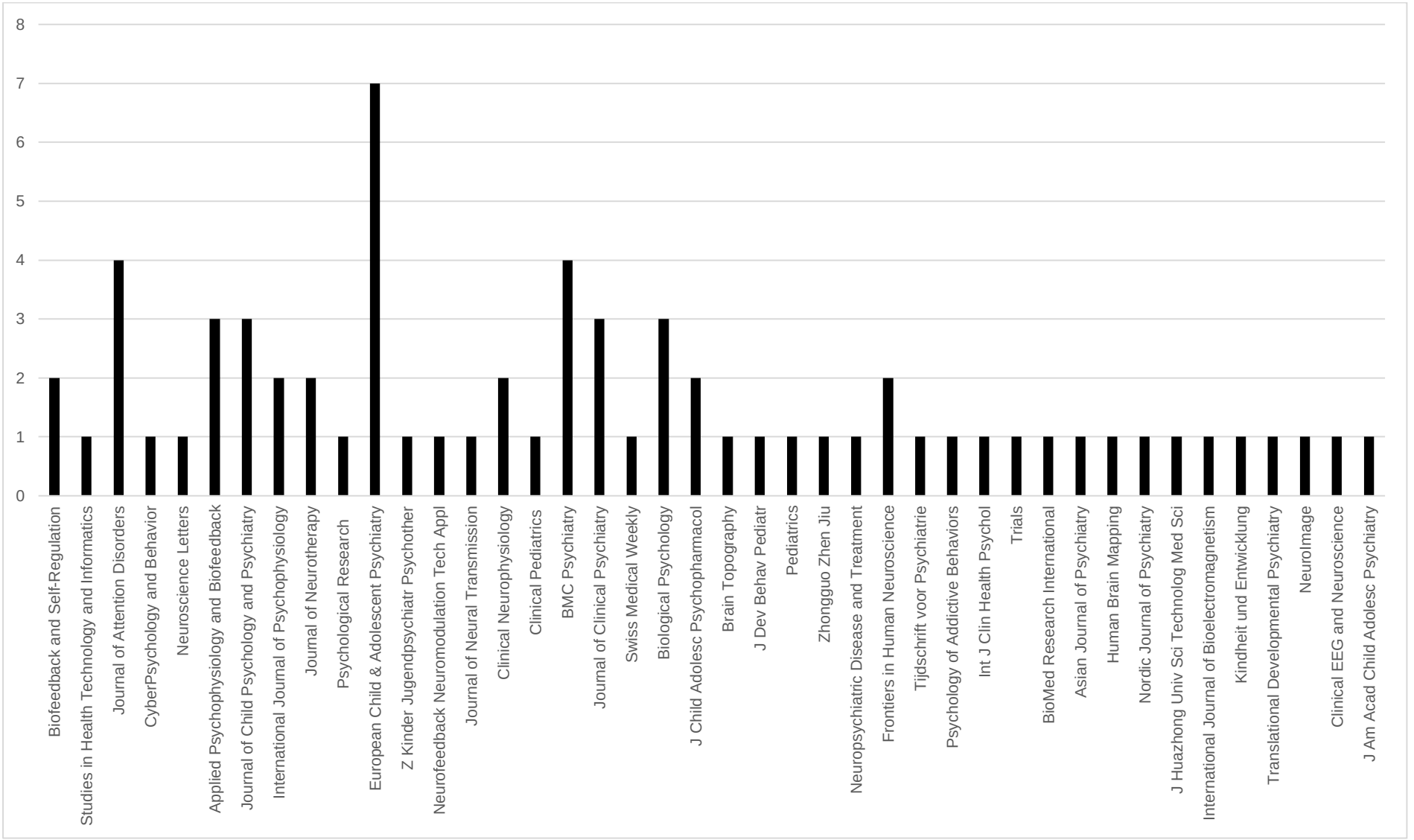
China; 3; 4%
Korea; 3; 4%
Switzerland; 3; 4%
New Zealand; 1; 1%
Canada; 3; 4%
Norway; 4; 6%
Germany; 16; 24%
Netherlands; 11; 16%
Iran; 2; 3%

Figure 4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Biofeedback and Self-Regulation
Studies in Health Technology and Informatics
Journal of Attention Disorders
CyberPsychology and Behavior
Neuroscience Letters
Applied Psychophysiology and Biofeedback
Journal of Child Psychology and Psychiatry
International Journal of Psychophysiology
Journal of Neurotherapy
Psychological Research
European Child & Adolescent Psychiatry
Z Kinder Jugendpsychiatr Psychother
Neurofeedback Neuromodulation Tech Appl
Journal of Neural Transmission
Clinical Neurophysiology
Clinical Pediatrics
BMC Psychiatry
Journal of Clinical Psychiatry
Swiss Medical Weekly
Biological Psychology
J Child Adolesc Psychopharmacol
Brain Topography
J Dev Behav Pediatr
Pediatrics
Zhongguo Zhen Jiu
Neuropsychiatric Disease and Treatment
Frontiers in Human Neuroscience
Tijdschrift voor Psychiatrie
Psychology of Addictive Behaviors
Int J Clin Health Psychol
Trials
BioMed Research International
Asian Journal of Psychiatry
Human Brain Mapping
Nordic Journal of Psychiatry
J Huazhong Univ Sci Technolog Med Sci
International Journal of Bioelectromagnetism
Kindheit und Entwicklung
Translational Developmental Psychiatry
NeuroImage
Clinical EEG and Neuroscience
J Am Acad Child Adolesc Psychiatry

Table 2

Synthesis of studies reviewed: randomized controlled trials. Design, participants and significant results.

	Participants						
Author/s (Year)	*n*	Age (Sex)	Subtype	Design	Total sessions/ weeks (duration/ session)	Evaluation instruments	Neurofeedback results
Lubar et al. (1995)*	23	8-19(35M; 6F)	----	3 Studies: Neurofeedback(TBR) 1.CPT(*n*=18). 2.Behavior Ratings(*n*=13). 3.IQ(*n*=10)	40ses.8-10wks(60')	TOVA.ADDES.WISC-R.	Comparing pre-post treatment, neurofeedback training showed significant differences in the 3 studies: 1. Significant improvement in T.O.V.A. performance in participants showing significant EEG changes in comparison with subjects

							without changes (t = 2.99, p < .01). 2. Significant clinical improvement in behavior ratings (measured by parents) in hyperactivity (t = -4.60, p < .0001), impulsivity (t = -6.596, p < .001), and inattention (t = -4.474, p < .001). 3. Significant increase in WISC-R performance, in IQ scores (verbal: t = -3.65, p < 005; full scale: t = -3.68, p < .005 and performance: t = -2.18, p < .05).
Linden et al. (1996)*	18	5-15	----	2 Groups: 1.Neurofeedback (TBR)(n=9).	40ses.24 wks/(45´)	K-BIT.IOWA-Conners.SNAP.	The neurofeedback group showed post-treatment

				2. Waiting List (*n*=9).			improvements of clinical significance. A significant increase of a mean of 9 points was observed on the K-Bit IQ Composite compared to the waiting list ($p < .05$).
Cho et al. (2002)*	50	14-18	----	5 Groups: Experimental: 1.Neurofeedback(TBR)(*n*=10). 2.CT (*n*=10). 3.Placebo(*n*=10). 4.Placebo CT(*n*=10). Control: 5.None(*n*=10).	8ses.24 wks (20')	CPT	Significant post-treatment improvement was obtained in CPT (more correct answers) in both groups ($F(1,32) = 93.760$, $p < .01$). Experimental groups improved more than placebo groups ($F(1,32) = 4.193$, $p < .05$). Neurofeedback groups showed more improvement than cognitive training groups ($F(1,32) = 3.121$, $p < .10$).
Heywood & Beale	7	7-12 (7M)	----	2 Groups:	60ses.24 wks	ADHD-	Both groups showed increased

(2003)*				1.Neurofeedback(SMR;TBR). 2.Placebo.	(20-40')	RS.CAP.CCT.CPT.PAL -T.CBCL.	clinical improvements. Placebo group showed relatively increased improvements, with small effect size (d = 0.24), in some cases.
Cho et al. (2004)*	28	14-18 (M)	----	3 Groups: 1.Neurofeedback-VR(TBR)(n=10). 2.Neurofeedback(TBR(n=9). 3. Waiting List(n=9).	8ses.2 wks(20')	CPT	Significant increase (p < .01) in selective attention, better information management and less impulsivity in neurofeedback groups. Comparing VR and non-VR groups, the effects group ($F(1,16) = 10.392$, $p < 0.01$) and time ($F(1,16) = 14.125$, $p < 0.01$) were significant.
Zhonggui et al. (2005)*	60	>6	I(n=20); H(n=20;	1 Group: Neurofeedback (SCP;SMR).	40ses.20wks /2(20')	IVA	Neurofeedback showed significant clinical

			C(*n*=20)				improvement in overall symptoms. IVA indexes resulted in significant improvement ($p < .001$).
Lévesque et al. (2006)*	20	8-12 (16M;4F)	----	2 Groups: 1. Neurofeedback(SMR;TBR)(*n*=15) 2.Control(*n* =5)	40ses.13.5 wks /3(60')	WISC-R.IVA.CPRS-R.	Neurofeedback resulted in brain activity changes (significant activation of the right ACC found only in the neurofeedback group). Neurofeedback led to clinical improvements by normalizing selective attention and response inhibition in children with ADHD compared to the control group. Comparing pre-post treatment measures, neurofeedback group showed significant increase on the Digit Span ($p < .05$), IVA

							scores ($p < .005$) and significant decrease (measured with the CPRS-R) on inattention ($p < .001$) and hyperactivity ($p < .05$).
Beauregard & Lévesque (2006)*	2	8-12 (16M;4F)	----	2 Groups: 1.Neurofeedback(SMR; TBR)(*n*=15). 2.Control(*n*=5).	40ses.13.5 wks /3(60')	WISC-R.IVA.CPRS-R.	Neurofeedback resulted in significant activation of right ACC, left caudate nucleus and left substantia nigra. Comparing pre-post treatment measures, neurofeedback group showed significant increase on the Digit Span ($p < .05$), IVA scores ($p < .005$) and significant decrease (measured with the CPRS-R) on inattention ($p < .001$) and hyperactivity ($p < .05$) resulting in behavioral and

							attentional improvements.
Leins et al. (2007)*	38	8-13(32M; 6F)	I(*n*=30); H(*n*=8)	2 Groups: 1.Neurofeedback(TBR). 2.Neurofeedback(SCP).	30ses.6 wks (60')	HAWIK-III.TAP.CRS.ECBI. ADHD-RS.	Neurofeedback led to significant improvement in ADHD symptoms, intelligence and other altered behavior maintained 6 months. Neurofeedback showed significant decrease in parental (Inattention: $F(2,68) = 9.15$, $p = .001$; Hyperactivity: $F(2,68) = 10.08$, $p < .001$; CRS: $F(2,62) = 7.75$, $p = .001$) and teachers (Hyperactivity: $F(2,64) = 6.58$, $p = .003$; Impulsivity: $F(2,64) = 5.43$, $p = .008$; Social behavior: $p = .010$) ratings over time. Both groups of neurofeedback resulted in

							significant improvement on IQ performance (F(1,35) = 31.11 , *p* = .002) and scale (F(1,35) = 11.39, *p* = .002). None showed significant time × group interaction nor differences between groups.
Gani et al. (2008)●	47	8-12 (38M;9F)	I(*n*=10); H(*n*=1); C(*n*=36)	2 Groups: 1.Neurofeedback(SCP)(*n*=25). 2.Neurofeedback(TBR)(*n*=22).	36 wks	TAP.CRS.ECBI.	Clinical outcomes and self-regulations skills were maintained at 2 years follow-up in both groups of neurofeedback. Significant decrease in parental ratings over time on measures of inattention (F (2, 40) = 16.40, *p* = .00), (F(2, 40) = 14.59, *p* = .00) and CRS (F (2, 40) = 8.277, *p* = .01). None showed significant time × group

							interaction nor significant difference between groups.
Holtmann et al. (2009)*	34	10.3 (31M;3F)	I(*n*=20); H(*n*=12); C(*n*=2)	2 Groups: 1.Neurofeedback(theta/beta)(*n*=20). 2.AST(*n*=14).	20ses.10 wks /1(30').	FBB-HKS	Neurofeedback showed relatively higher-effects in comparison. Improvements were reported along groups and time. No significant differences were reported between them. Improvements in the main ADHD symptoms were inattention (*d* = 0.40), hyperactivity (*d* = 0.13) and impulsivity (*d*= 0.14).
Gevensleben, Holl, Albretch, Vogel et al. (2009)*	94	8-12 (77M; 17F)	I(*n*=28); C(*n*=66)	2 Groups: 1.Neurofeedback(TBR;SCP). 2.AST.	36ses.6-8 wks /4-6(50')	FBB-HKS.SDQ.HSQ.HPC	Significant improvement was shown by the neurofeedback group, which resulted in better parent and teacher ratings than the AST group. The effect size

							was *d* = 0.60 for the primary outcome measure in the FBB-HKS. Both neurofeedback protocols (SCP and TBR) obtained similar effects.
Gevensleben, Holl, Albrecht, Schlamp et al. (2009)*	72	8-12 (61M;11F)	I(*n*=24); C(*n*=48)	2 Groups: 1.Neurofeedback(TBR;SCP)(*n*=46) 2.AST(*n*=26).	36ses.6-8 wks /4-6(50')	FBB-HKS	Both groups resulted in significant clinical improvement of the main ADHD symptoms. Neurofeedback group obtained superior improvement compared to AST, with an effect size of *d* = 0.60. The superiority of FBB-HKS inattention and hyperactivity/impulsivity in neurofeedback group was of 25-30%. These results maintained 6 months follow-

							up.
Perreau-Linck et al. (2010)*	9	8-13(8M;1F)	C	2 Groups: 1.Neurofeedback(SMR;TBR). 2.Placebo.	40ses.7-9 wks /3(60')	CPRS-R:L.CPT–II.BADS-C.CAT.TEA-ch.D2.	Significant improvements were found on the CPRS–R and CPT–II on both groups. Neurofeedback showed inhibition improvement and superiority effects. No effect sizes were reported.
Bakhshayesh et al. (2010)*	35	6-14 (26M;91F)	----	2 Groups: 1. Neurofeedback (TBR)(*n*=18). 2.Placebo (*n*=17).	30ses.	----	Neurofeedback resulted in a clinically effective treatment in comparison to placebo. Improvement in ADHD symptoms was found in 55.6% of cases.
Gevensleben, Holl et al. (2010)*	94	8-12 (77M;17F)	I(*n*=28); C(*n*=66)	2 Groups: 1. Neurofeedback(TBR;SCP) (*n*=38).	36ses.6-8 wks /4-6(50')	FBB-HKS.FBB-SSV.SDQ.HSQ.HPC.	Neurofeeback group obtained better results than AST group, showing a significant group effect in the primary outcome

				2.AST (*n*=23).			measure (F(1,58) = 10.10, p < 0.005). A medium effect size of d = 0.71 was found 6 months follow-up demonstrating that neurofeedback is a clinically efficacious module.
Gevensleben, Moll, et al. (2010)*	94	8-12 (75M;19F)	----	2 Groups: 1.Neurofeedback(TBR;SCP) (*n*=59). 2.AST(n=35).	36ses.6-8 wks /4(50')	FBB-HKS.FBB-SSV.SDQ.HSQ.HPC.	Neurofeedback group obtained higher improvements in ADHD core and associated symptoms, in FBB-HKS with an effect size of d = 0.60, maintained 6 months follow-up, demonstrating that neurofeedback is a clinically efficacious module.
DeBeus & Kaiser (2011)*	42	7-12 (13M;29F)	I(*n*=18); C(*n*=24)	2 Groups: 1.Neurofeedback(alpha;beta;SMR)	20ses.10 wks /2(30')	CTRS-R:L.CPRS-R:L.IVA.	Neurofeedback showed significant clinical

				(*n*=42). 2.Placebo(*n*=42).			improvement in the main symptoms of ADHD. Neurofeedback group resulted in better scores in CTRS-R (*d* = 0.50) and in IVA (*d* ≈ 0.60). No treatment effects were reported on CPRS-R.
Lansbergen et al. (2011)*	14	8-15 (13M; 1F)	I(*n*=7); H(*n*=7)	2 Groups: 1.Neurofeedback(SMR;TBR). 2.Placebo.	30ses.16 wks /2(45')	PSERS.SDQ.CGI.	Significant improvement over time in the neurofeedback group in comparison to placebo, in decreasing inattention (F(4,48) = 22.07, *p* < .001) and hyperactivity/impulsivity (F(4,48) = 8.09, *p* < 001). Maintained 6 months follow-up.
Wangler et al.	94	8-12 (77M;	I(*n*=28);	2 Groups:	36ses.6-8 wks	FBB-HKS	Significant improvement in

(2011)*		17F)	C(*n*=66)	1.Neurofeedback(TBR;SCP)(*n*=59). 2.AST(*n*=35).	/4-6(25-30´)		the primary symptoms (FBB-HKS) with neurofeedback training, especially SCP training, which 30% of its variance (R^2 = .286) could have been explained by the predictors CNV (β = .409, p < .005) and alpha activity (β= .262, p < .1).
Steiner et al. (2011)*	41	12 (21M; 20F)	----	3 Groups: 1.Neurofeedback(TBR)(*n*=13). 2.SCF(*n*=13). 3.Waiting list(*n*=15).	23ses.16 wks /2 (45')	CRS-R.BRIEF.BASC-2. IVA-CPT.	Significant improvement comparing pre-post neurofeedback training in CRS-R and BASC, with an effect size of p < .05. In the SCF module this effect size p < .05 was also maintained in CRS-R, BASC and BRIEF.
Bakhshayesh et al.	35	6-14	I(*n*=29)	2 Groups:	30ses.10-15 wks	FBB-	Neurofeedback training

(2011)*		(26M;9F)		1.Neurofeedback(TBR)(*n*=18). 2.EMG-BF(muscular relaxation)(n=17).	/2-3(30')	HKS.CPT.BP.D2.FBB-SSV.SDQ.HSQ.HPC.	resulted in higher significant clinical improvement in ADHD core symptoms. Parents reported better scores in neurofeedback group compared to EMG-BF (*d* = -0.94).
Duric et al. (2012)*	91	6-18 (72M; 19F)	----	3 Groups: 1.Neurofeedback(TBR)(*n*=30). 2.MED(MTF)(*n*=31). 3.Neurofeedback+MED(MTF)(*n*=30).	30ses. 3/ wks (40')	CBCL	Significant changes were informed by parents in all scales within the three groups ($p < .001$). No significant changes were reported between groups.
Liechti et al. (2012)*	13	8-13 (11M; 2F)	C	3 Groups: 1.Neurofeedback-tomographic(TBR;SCP)(*n*=13). 2.Neurofeedback. 3.EMG-BF.	36ses.9-12 wks /2(60')	FBB-HKS.CPRS.SDQ.BRIEF .CTRS.CBCL.HAWIK-IV.D2.	Neurofeedback groups showed significant improvement in ADHD symptoms reported by teachers ($F(5,8) = 4.009$, $p = .041$) with medium effect sizes

							and parents (F(9,4) = 9.056, *p* = .024) with medium to large effects.
Russell-Chapin et al. (2013)●	12	9-15(11M; 1F)	----	2 Groups: 1.Neurofeedback(SMR). 2.Usual treatment	40ses.13 wks (20')	TOVA	Significant-improvement between the first and last session using neurofeedback (*t* (5) = -1.83, *p* = .05).
Arnold et al. (2013)*	39	6-12(31M; 8F)	I(*n*=13); C(*n*=26)	2 Groups: 1.Neurofeedback(TBR;SMR)(*n*=26) 2. Placebo(*n*=13).	30ses.10-15 wks /2- 3(45')	SNAP.CRS-R.BRIEF.IRS.CGI.WIAT-II.WASI.	Both groups improved. No significant differences between treatments were obtained.
Kerson (2013)*	180	7-10	----	2 Groups: 1.Neurofeedback(TBR)(*n*=108). 2.Placebo(*n*=72).	38ses.13 wks /3	ChIPS.C-3.IRS.CSHQ.CGI.WASI-II.WIAT-II.IVA.CPT.	RCT Proposal. Includes Training Protocol.
van Dongen-Boomsma et al. (2013)*	41	8-15 (34M; 7F)	I(*n*=9); H(*n*=2); C(*n*=30)	2 Groups: 1.Neurofeedback(SMR;TBR)(*n*=22) 2.Placebo(*n*=19).	30ses.12 wks /2(20')	ADHD-RS.CGI.CGAS.SDQ.PSERS.	Both groups showed significant clinical improvements ($p < .001$). No

							significant effect was found due to group x time interaction (F(1,39) = 0.36, *p* = .554).
Li et al. (2013)*	64	7-16 (54M;10F)	I(*n*=42); H(*n*=3); C(*n*=19)	2 Groups: 1.Neurofeedback(TBR;SMR)+MED (MTF)(*n*=32). 2.MED(MTF) (*n*=32).	40ses.20 wks /2-5(25-35')	CPT.RCBQ.ACBC.PIAS.SRC.GAF.	Combined group including neurofeedback showed significantly (*p* <0.05) better post-treatment outcomes, improving parents and teacher's ratings on hyperactivity/impulsivity and total ADHD. Drug dose decreased in the combined group.
Meisel et al. (2013)*	23	7-14 (11M;12F)	I(*n*=5); C(*n*=18)	2 Groups: 1.Neurofeedback(TBR)(*n*=12). 2.MED(MTF)(*n*=11).	40ses.20 wks /2(35')	ADHD-RS.TND-scale.CBCL.WISC-IV.WFIRS.	Both groups significantly improved comparing pre-post treatment. No significant differences were found between treatments.

							Neurofeedback group showed highly significant ($p < .001$) improvements in core symptoms of ADHD rated by mothers, with large effect size ($d = 1.90$). In WFIRS, parents ratings significantly decreased, with a large effect size ($d = 0.68$). Maintained 2-6 months follow-up with medium to large effects.
Ogrim & Hestad (2013)*	29	7-16 (18M;11F)	I(*n*=7); C(*n*=22)	2 Groups: 1.Neurofeedback(TBR;SMR)(*n*=14) 2.MED(MTF;D-AFM)(*n*=15).	30ses.28-44 wks /2(45')	CRS-R.BRIEF.CPT	Significant differences between both groups, showing higher improved outcomes in primary ADHD symptoms rated by parents ($p = 0.033$) and teachers ($p = 0.015$) with large effect sizes, respectively, $d = 1.11$ and $d = 1.12$ in MED

							group.
Vollebregt et al. (2014)*	41	8-15(34M; 7F)	I(*n*=9); H(*n*=2); C(*n*=30)	2 Groups: 1.Neurofeedback(SMR;TBR)(*n*=22) 2.Placebo(*n*=19).	30ses.12 wks /2(20')	SA-DOTS.VSS.WISC-III.RAVLT.	Both treatment groups showed no significant differences in the measured variables.
Maurizio et al. (2014)*	25	8-13 (22M; 3F)	C	2 Groups: 1.Neurofeedback(TBR)(*n*=13). 2.EMG-BF(*n*=12).	36ses.12 wks /2-3(60')	FBB-HKS.CPRS.SDQ.BRIEF .CTRS	Significant clinical improvement in primary ADHD symptoms was shown in both groups. Neurofeedback group obtained better scores in the total parental FBB-HKS (d = 0.52), inattention (d = 0.72) and hyperactivity/impulsivity (d = 0.36) with higher medium effect sizes.
Gevensleben et al. (2014)*	40	9-16 (38M; 2F)	I(*n*=5); C(*n*=5)	2 Studies: 1.Neurofeedback(SCP).	13-24ses.24 wks /1-8(50')	FBB-HKS. ADHD-DSM-IV.FBB-	Neurofeedback showed significant improvement in inattention (d = 1.00) and

				2.Neurofeedback(TBR).		SSV.HPC.YTSS.	hyperactivity/impulsivity (*d* = 0.43).
Steiner et al. (2014)*	102	12 (69M;33F)	----	3 Groups: 1.Neurofeedback(TBR)(*n*=34). 2.CT(*n*=32). 3.Control(*n*=36).	40ses.20 wks /3(45´)	CRS.SKAMP.BRIEF.BOSS.	Neurofeedback group presented significantly improved outcomes compared to CT and control groups. Improvement was rated by parents in inattention (*p* = .001) and executive functioning (*p* = .001), and teachers, with an effect size of *d* = 0.25 in inattention. Neurofeedback group resulted in better engagement behavior in BOSS ratings (*d* = 0.25).
Steiner et al. (2014)*	102	7-1 (69M;33F)	----	3 Groups: 1.Neurofeedback(TBR)(*n*=34). 2.CT(*n*=32).	40ses.20 wks /3(45')	CRS.BRIEF.BOSS.	Neurofeedback group showed significant improvement in inattention (*d* = 0.34),

				3.Control(n=36).			executive functioning (*d* = 0.25), hyperactivity/impulsivity (*d* = 0.23) and BRIEF subscales (*d* = 0.31), maintained 6 months follow-up.
Holtmann et al. (2014)●	144	7-9	C	2 Groups: 1.Neurofeedback(SCP)(*n*=72). 2.EMG-BF(*n*=72)	25ses.12 wks /2-3(60')	FBB-ADHS.CGI.TAP.SDQ.CPM.KINDL-R.	Neurofeedback group obtained better results in comparison to EMG-BF. No further statistical data were reported.
He et al. (2014)●	94	----	----	2 Groups: 1.Acupuncture+neurofeedback(*n*=47)2.Neurofeedback(*n*=48)	4ses.	WISC.CRS.IVA.	Both groups showed significant improvement in all measures after treatment ($p < .01$, $p < .05$). Combined group obtained a higher efficacy rate (91.5%) in comparison with the unique treatment (83.3%).

Bink et al. (2014)*	71	12-24(71V)	----	2 Groups: 1.MED+Neurofeedback(TBR;SMR) (*n*=45). 2.MED(*n*=26)	37ses.25 wks /2-3(30')	ADHD-RS.YSR.CBCL.D2.WASI-IV.	Significant improvement in outcomes (attention, processing time and motor speed) at post-intervention for both groups with medium to large effect sizes (n_p^2 = 0.08-0.54, p < .023).
Duric et al. (2014)*	80	6-17(65V;15M)	----	3 Groups: 1.Neurofeedback(TBR)(*n*=28). 2.Neurofeedback(TBR)+MED (MTF)(*n*=25). 3.MED(MTF) (n=27).	30ses.11-13 wks /3(45')	SRQ	Significant improvement with effects in attention and hyperactivity (p < .001) for all the groups. Neurofeedback showed medium to large effect sizes in inattention (d = 0.90), hyperactivity (d = 0.57) and school performance (d = 0.55).
Christiansen et al. (2014)*	58	7-11(48V;10	----	2 Groups: 1.Neurofeedback(SCP)(*n*=28).	30ses.12 wks /3(60')	CRS.Qb-test.KITAP.CASSS.PS.	Clinical improvement in ADHD symptoms in both

		M)		2.SMR(*n*=30).		KINDL-R.PC.ESF.	groups. Both treatments resulted in adequate pre-post effects (n^2 = 0.175-0.513). No statistical differences were found between NF and SMR (p = .81).

van Dongen-Boomsma et al. (2015)*	41	5-7(34V;7M)	----	2 Studies:
				1.Neurofeedback(*n*=22)//Placebo (*n*=19).
				2.AST(*n*=27)//Placebo(*n*=24).
					25-30 wks /2-5	ADHD-RS.CGI.CGAS.PSERS. SDQ.	Both treatments clinically improved in ADHD symptoms. No significant differences were found between groups.

Keith et al. (2015)*	95	18-56(59V;36 M)	----	3 Groups: 1.Neurofeedback(auto)(TBR;SMR) (*n*=30). 2.Neurofeedback(clinical) (TBR; SMR)(n=33). 3.Usual treatment+therapy (n=32).	15ses.1.5 wks /5(30')	TOVA	Both neurofeedback groups showed significant improvement in EEG measures in comparison to the usual treatment group with medium to large effects (d = 0.53-0.93).

Bink et al. (2015)*	71	12-24	----	2 Groups: 1.Neurofeedback(TBR;SMR)+MED (*n*=45). 2.MED(*n*=26).	37ses.25 wks /2(30')	ADHD-RS.CBCL.YSR.	Behavioral problems were significantly improved similarly in both groups with medium to large effect sizes (η^2 = 0.08-0.31, p <.05).
Moreno-García et al. (2015)*	57	7-14(44V;13 M)	I(*n*=27); H(*n*=10; C(*n*=20)	3 Groups: 1.Neurofeedback(TBR)(*n*=19). 2.MED(MTF) (*n*=19). 3.BT(*n*=19).	30ses.20 wks /4(24')	IVA	Significant improvement in all groups, in auditory attention (p =.017), global attention (p =.002) and visual attention (p =.028). Not statistical differences were found between groups.
Janssen et al. (2016)*	103	7-13	----	3 Groups: 1.Neurofeedback(TBR)(*n*=38). 2.MED(MTF)(*n*=31). 3.PA(*n*=34).	30ses.10 wks /3(45')	----	Significant improved response inhibition with medication (p < .001) in comparison to neurofeedback (p =.240) and physical activity (p = .425).
Hasslinger et al.	200	9-17	----	4 Groups:	25ses.5 wks /5	CRS.CPT-II.WISC-	RCT Proposal. Includes

(2016)●				1.Neurofeedback(SCP)(*n*=50). 2.Neurofeedback(LZS)(*n*=50). 3.WMt(*n*=50).4.Waiting List(*n*=50).	(40')	IV.WASI-IV.BRIEF.KIDSCREEN-27.CPT.SPSQ.	Training Protocol.
Geladé et al. (2016)*	103	7-13(85V;27 M)	----	3 Groups: 1.Neurofeedback(TBR)(*n*=38). 2.MED(MTF)(*n*=31). 3.PA(*n*=34).	19-30ses.10-12 wks /3(45')	DBDRS.SDQ.SWAN.	The three treatments showed improved outcomes. Parent's ratings, in the three groups, showed a significant decrease in hyperactivity/impulsivity in SDQ and SWAN (n_p^2= 0.21-0.22, $p \leq .001$). Inattention improved in MED group compared to neurofeedback or PA (respectively, n_p^2= 0.13, $p \leq .001$ and n_p^2= 0.14-0.29, $p < .001$).
Blume et al. (2017)●	90	6-10	----	3 Groups: 1.Neurofeedback(VR)(*n*=30). 2.Neurofeedback(*n*=30).	15ses.(60-70')	CFT.CRS.SDQ.KINDL-R.SCS-K-D. BRIEF.FERT.WISC-	RCT Proposal. Includes Training Protocol.

				3.EMG-BF(VR)(*n*=30).		IV.VFT.CPT.LVD-M.SLRT-II.	
Mohagheghi et al. (2017)*	54	7-10	C	2 Groups: 1.Neurofeedback(TBR)(*n*=26). 2.Neurofeedback(theta/alfa)(*n*=28).	40ses/3(45')	CPRS.K-SADS-PL.ADHD-RS.CPRS-R.CPT-II.	Both neurofeedback groups showed significant improvement in ADHD total scores ($p < .001$), inattention ($p < .001$), hyperactivity ($p < .001$) and omission errors ($p < .001$), maintained 2 months follow-up.
Lee & Jung (2017)*	36	6-12 (28M;9F)	I(*n*=15); H(*n*=5); C(*n*=16)	2 Groups: 1.Neurofeedback(TBR;SMR)+MED (*n*=18). 2.MED(*n*=18).	20ses.10 wks /2(60')	ADS.ARS.K-WISC-III.ADHD-RS.	Combined group obtained significantly ($p < .01$) higher improved parent ADHD ratings with an effect size of $d = 0.98$.
Strehl et al. (2017)*	144	7-9 (119M; 25F)	C	2 Groups: 1.Neurofeedback(SCP)(*n*=75). 2.EMG-FB(*n*=69).	25ses.12 wks /2-3	ADHD-RS.CGI.SDQ.IQ.KIND-R.	Both groups resulted in significant decrease of ADHD core symptoms.

							Neurofeedback group obtained better outcomes compared to EMG-BF (p = .02) with an effect size of d = 0.57.
Geladé et al. (2017)*	103	7-13 (85M;27F)	----	3 Groups: 1.Neurofeedback(TBR)(n=38). 2.MED(MTF)(n=31). 3.PA(n=34) .	30ses.10-12 wks /3(45')	DBDRS.SDQ.SWAN.	Combined group improved significantly in outcomes, impulsivity, inhibition and attention (η_p^2 = 0.09-0.18, p < .008), in comparison to MED and PA. Working memory showed significant improvements in all groups (η_p^2 = 0.17, p < .001).
Janssen et al. (2017)*	38	7-13 (29M;9F)	----	3 Groups: 1.Neurofeedback(TBR)(n=38).2.MED(MTF)(n=31).3.PA(n=34).	29ses.10-12 wks /3(45')	DBDRS.SDQ.SWAN.	Significant improvement in ADHD scores (p < .001) using neurofeedback. No correlates between these behavioral measures and the EEG

							individual learning curves were found.
Alegría et al. (2017)*	31	12-17 (31M)	I(*n*=4); C(*n*=27)	2 Groups: 1.Real-time fMRI-Neurofeedback(rIFG)(*n*=19).2. Real-time fMRI-Neurofeedback(lPHG)(*n*=12).	14ses.2 wks /2 (60-65')	ADHD-RS.CPRS-R.WREMB-R.CIS.MARS.	Pre-post treatment with neurofeedback resulted in decreased ADHD symptoms within groups and were maintained 11 months follow-up. Improvements in outcomes were decreased primary ADHD symptoms (inattention: $F(1,2) = 19.85$, $p < 0001$, $d = 0.79$; hyperactivity/impulsivity: $F(1,29) = 12.33$, $p < .001$, $d = 0.49$; total ADHD score: $F(1,29) = 20.41$, $p < .001$, $d = 0.69$) and secondary outcomes ($F(1,29) = 18.25$, $p < .001$, $d =$

							0.73).
Johnstone et al. (2017)*	8	8-13 (64M;21F)	----	2 Groups: 1.WMt+IQ+neurofeedback(delta;alpha;TBR)(*n*=44).2.Waiting List(*n*=41).	25ses.6-8 wks /3-4(20')	ADHD-RS.CRS.CBCL.WIAT-II.	Neurofeedback group showed a clinical significant improvement in main ADHD symptoms compared to the waiting list group. Neurofeedback resulted in better ratings in hyperactivity/impulsivity (F(1,80) = 9.571, p = .003, η_p^2 = 0.11), inattention (F(1,80) = 5.375, p = .023, η_p^2 = 0.07), and executive functions (F(1,80) = 12.122, p =.001, η_p^2 = 0.14).
Duric et al. (2017)●	81	6-18 (72M;9F)	----	3 Groups: 1.Neurofeedback(SMR;TBR;EMG) (*n*=24).2.Neurofeedback(SMR;TBR	30ses./3	ECBI.SRQ.	Significant improvement was observed within each treatment group (p = .01).

				;EMG)+MED(MTF)(*n*=29).3.MED(MTF)(*n*=28).			Parent's and teacher's ratings in the three treatment groups showed significant improvement in inattention, obtaining the combined group better scores (respectively, p = .01 and p = .02). Clinical effects were maintained 6 months follow-up.
Döpfner et al. (2017)*	521	6-11	----	7 Groups: 1.PA+MED. 2.TASH. 3. Waiting List. 4.MED+Counseling. 5.MED+BT. 6.MED+Neurofeedback(SCP).7. BT.	25ses. (60')	DCL-ADHS.DCL-SSV.CGI.FBB-ADHS.FBB-SSV.CBCL.WFIRS-P.SRS.CPT.	RCT Proposal. Includes Training Protocol.
Geladé et al. (2018)*	92	7-13(70V;22	----	3 Groups: 1.Neurofeedback(TBR)(*n*=33).	30ses.10-12wks/3(45´)	SDQ.SWAN.SDSC.	No significant group differences were found in

		M)		2.MED(MTF)(*n*=28). 3.PA(*n*=31)			ADHD measures (p = .058-.997), except for higher improved inhibition in MED group compared to neurofeedback and PA (p = .040). At 6 months follow-up, this superiority became smaller or non-significant.
Minder et al. (2018)*	77	8-15(50V;27 M)	----	2 Groups: 1.Neurofeedback(SCP)(*n*=38). 2.CT (*n*=39).	10-14 wks / 1-6(45-60´)	CRS.BRIEF.BOSS.	Both groups showed significant clinical improvements in ADHD symptoms. Parent's ratings presented larger effect size effects (η_p^2 = .32) than teacher's ratings (η_p^2 = .10).
Moreno-García et al. (2019)*	57	7-14(44V;13 M)	I(*n*=27); H(*n*=10; C(*n*=20)	3 Groups: 1.Neurofeedback(TBR)(*n*=19). 2.BT(*n*=19).	40ses.20 wks/4 (24')	IVA.ADHD-RS.ADDES.	Both groups resulted in significant improvement on overall measures, with effect

				3.MED(*n*=19).			sizes between *d* = 0.47-1.03. Neurofeedback showed larger average global effect size in IVA/CPT (*d* = 0.80).
Rubia et al. (2019)*	31	12-17(31V)	I(*n*=4); C(*n*=27)	2 Groups: 1.fMRI-neurofeedback(rIFC)(*n*=18). 2. Real-time fMRI-neurofeedback(lPHG)(*n*=13).	11ses.2wks /4 (60-90´)	ADHD-RS.CPRS.	Both groups showed significant clinical improvement in ADHD symptoms. Ratings in all measures were improved showing medium to large effect sizes (*d* = 0.43-1.08).
Bioulac et al. (2019)*	179	7-13	----	2 Groups: 1.Neurofeedback(SMR;TBR). 2.MED(MTF)	36ses.9 wks /4 (<30´)	ADHD-RS.BRIEF.SDQ.CGI.PAERS.SSRS.SDSC.CPT.	RCT Proposal. Includes Training Protocol.
Dobrakowski & Lebecka (2020)*	48	6-12 (37V;11M)	----	2 Groups: 1.Neurofeedback(TBR)(*n*=34). 2.Control(*n*=36).	10-12ses.10 wks /1 (45´)	n-back Test.MOXO-test	Neurofeedback group resulted in a significant improvement in working memory ($p < .001$) with a large effect size (*d* =

							1.22) in comparison to the control group.
Purper-Ouakil et al. (2021)●	178	7-13	----	2 Groups: 1.Neurofeedback(SMR; TBR)(*n*=111). 2.MED(MTF)(*n*=67).	36ses.9 wks /4 (<30´)	ADHD-RS.BRIEF.SDQ.CGI.PAERS.SSRS.SDSC.CPT-3.CHIP-CE.	Both groups showed significant pre-post clinical improvements in primary ADHD symptoms and secondary outcomes. Neurofeedback showed significant better scores in ADHD-RS-P hyperactivity/impulsivity (*p* = .03) and SDQ hyperactivity (*p* = . 04). In the intermediate and final session, neurofeedback's effects increased in comparison to MED group which maintained stable.

Neurofeedback Collaborative Group (2021)*	144	7-10 (111V;31 M)	I(*n*=51); C(*n*=91)	2 Groups: 1.Neurofeedback(TBR)(*n*=84). 2.Control(*n*=58).	38ses.14 wks (25´)	CRS-R CGI FAC	Both groups showed significant improvement ($p <$ .001, $d = 1.5$) in parent's and teacher's ratings for inattention, maintained 13 months follow up. Neurofeedback group required significantly less medication in follow-up ($p = .012$).
Aggensteiner et al. (2021)*	103	7-9	C	2 Groups: 1.Neurofeedback(SCP)(*n*=50). 2.EMG-BF(*n*=53)	25ses.12 wks /2-3(60')	FBB-HKS.CPT	Both groups showed significant improvements in all scales ($p = .05$). Neurofeedback group resulted in higher global and inattention parent´s rates ($F(1,65) \geq 5.00$, $p = .03$, $\eta_p^2 \geq .07$).

Notes: Publications included in the database search are marked with an * and those included in the complementary search are marked ●.
AFM=Amphetamine; C=Combined; D-AFM=Dextroamphetamine; H=Hyperactivity/Impulsivity; I=Inattention; F=Female; MTF = Methylphenidate; Wks=Weeks; Ses=Sessions; TBR= theta/beta ratio; M=Male.

Table 3

List of instruments, evaluation techniques used and treatments administered in the studies reviewed

Abbreviation	Definition
ACBC	Achenbach Child Behavior Checklist
ACC	Anterior Cingulate Cortex
ADDES	Attention Deficit Disorder Evaluation Scale
ADHD-RS	Attention Deficit and Hyperactivity Disorder Rating Scale
ADS	ADHD Diagnostic System
AFM	Amphetamine
ARS	ADHD Rating Scale for Parents
AST	Attention Skills Training
BADS-C	Behavior Assessment of Dysexecutive Syndrome - Children
BASC-2	Behavior Assessment System for Children - Second Edition
BF	Biofeedback
BOSS	Blinded Classroom Observation
BP	BP Attention Test (Basisdiagnostik Umschriebener Entwicklungsstörungen im Grundschulalter)
BRIEF	Brief Rating Inventory of Executive Functioning
BT	Behavior Training
CAP	Child Attention Profile
CASSS	Child and Adolescent Social Support Scale
CAT	Children´s Apperception Test (Brown-Peterson)
CBCL	Child Behavior Checklist (Barkley)
CCT	Children's Checking Task
CFT	Culture Fair Intelligence Test
CGAS	Children's Global Assessment Scale
CGI	Clinical Global Impression
CHIP-CE	Child Report Form of the Child Health and Illness Profile-Child Edition
ChIPS	Children's Interview for Psychiatric Syndromes

CIS	Columbia Impairment Scale-Parent Version
CPM	Raven's Colored Progressive Matrices
CPRS-R:L	Conners Parent Rating Scale - Revised, Long Version
CPT	Continuous Performance Task
CRS-R	Conners' Rating Scales - Revised
CSHQ	Children's Sleep Habits Questionnaire
C-SSRS	Columbia Suicide Severity Rating Scale
CT	Cognitive Training
CTRS-R:L	Conners Teacher Rating Scale - Revised, Long Version
D2	D2 Attention Test (Aufmerksamkeits-Belastungs-Test)*
D-AFM	Dextroamphetamine
DBDRS	Disruptive Behaviour Disorder Rating Scale
DCL-ADHS	Diagnose-Checkliste Aufmerksamkeitsdefizit- / Hyperaktivitätsstörungen aus dem Diagnostik-System DISYPS
DCL-SSV	Diagnose-Checkliste Störungen des Sozialverhaltens aus dem Diagnostik-System DISYPS
ECBI	Eyberg Child Behavior Inventory
EMG	Electromyography
ESF	Eltern-Stress-Fragebogen
FAC	Functional Assessment Checklist
FBB-ADHS	Fremdbeurteilungsbogen für Aufmerksamkeitsdefizit- / Hyperaktivitätsstörungen
FBB-HKS	Fremdbeurteilungsbogen für Hyperkinetische Störungen
FBB-SSV	Fremdbeurteilungsbogen für Störungen des Sozialverhaltens
FERT	Fragebogen zur Erfassung relevanter Therapiebedigungen
fMRI	functional Magnetic Resonance Imaging
GAF	Global Assessment of Functioning Scale
HAWIK-III	Hamburg-Wechsler-Intelligenztestfür Kinder - Dritte Auflage
HPC	Homework Problem Checklist
HSQ	Humor Styles Questionnaire
IOWA-Conners	IOWA-Conners Behavior Rating Scale

IQ	Intelligence Quotient
IRS	Impairment Rating Scale
IVA	Integrated Visual Auditory Continuous Performance Test
K-BIT	Kaufman Brief Intelligence Test
KIDSCREEN-27	Erfassung der Gesundheitsbezogenen Lebensqualität von Kindern und Jugendlichen (Kürzere Version des KIDSCREEN-52)
KINDL-R	Revidierter Fragebogen für Kinder und Jugendliche zur Erfassung der Gesundheitsbezogenen Lebensqualität
KITAP	Children's Test-Battery of Attention Assessment
K-SADS-PL	Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime version
K-WISC-III	Korean-Wechsler Intelligence Scale for Children-III
lPHG	left Parahippocampal Gyrus
LVD	Lernverlaufsdiagnostik-Mathematik
LZS	Live Z-Score
MARS	Maudsley Attention and Response Suppression Task Battery
MED	Medication Treatment
MOXO-Test	Computer-based MOXO-d-CPT Test2
MTF	Methylphenidate
NFT	Neurofeedback Treatment
ODD-Scale	Oppositional Defiant Disorder Scale
PA	Physical Activity
PAERS	Pediatric Adverse Event Rating Scale
PAL-T	Paired Associate Learning Task
PC	Perceived Criticism Scale
PIAS	Peer Interactions Assessment Scale
PS	Parenting Scale
PSERS	Pittsburgh Side Effects Rating Scale
Qb-Test	Combined-CPT
RAVLT	Rey Auditory-Verbal Learning Test

RCBQ	Rutter Children's Behavior Questionnaire
RCQ	Response Control Quotient
rIFC	right Inferior Frontal Cortex
rIFG	right Inferior Prefrontal Cortex
SA-DOTS	Sustained Attention Dots Task
SCF	Standard Computer Format
SCP	Slow Cortical Potentials
SCS-K-D	Selbstkontroll-Kapazität
SDQ	Strengths and Differences Questionnaire
SDSC	Sleep Disturbance Scale
SKAMP	Swanson, Kotkin, Agler, M-Flynn, and Pelham Scale
SLRT-II	Lese-und-Rechtschreibtest
SMR	Sensorimotor-Rhythm
SNAP	Swanson, Nolan, and Pelham (SNAP) Rating Scales (version of the DSM criteria by Swanson)
SPSQ	Swedish Parenthood Stress Questionnaire
SRC	School Report Card
SRQ	Self-Regulation Questionnaire
SRS	Social Responsiveness Scale
SWAN	Strengths and Weaknesses of ADHD Symptoms and Normal Behavior
TAP	Testbatterie-Aufmerksamkeitsprüfung
TASH	Telephone-Assisted Self-Help
TBR	Theta/Beta Ratio
TEA-ch	Test of Everyday Attention for Children
TOVA	Test of Variables of Attention
VFT	Verbal Fluency Task
VR	Virtual Reality
VSS	Visuospatial Sequencing
WASI	Wechsler Abbreviated Scale of Intelligence
WFIRS	Weiss Functional Impairment Rating Scale

WIAT-II	Wechsler Individual Achievement Test- Second Edition
WISC-IV	Wechsler Intelligence Scale for Children
WMt	Working Memory Training
WREMB-R	Weekly Rating of Evening and Morning Behavior-Revised
YSR	Youth Self-Report
YTSS	Yale Tourette Symptom Scale